Optimization of Damage Index in RC Structures Using Genetic Algorithm

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ABSTRACT :

The aim of this research is to use Genetic Algorithm in optimal design of reinforced concrete frames. During design of structures, different parameters like stress in members, deflection of members, inter-story drifts and etc. are considered. In this research damage index as a design parameter has been used and with minimizing damage index as a constraint, the total weight of structure has been minimized. The Park model has been applied as a damage estimating model. Also the computer program, IDARC, has been used for evaluating fitness function with different size of beams and columns and different steel areas.

KEYWORDS: Optimization, Damage Index, RC Structures, Genetic Algorithm

1. INTRODUCTION

In performance assessment and design verification of building structures, approximate nonlinear static procedures (NSPs) are becoming commonplace in engineering practice to estimate seismic demands. In fact, some seismic codes have begun to include them to aid in performance assessment of structural systems. Although seismic demands are best estimated using nonlinear time-history (NTH) analyses, NSPs are frequently used in ordinary engineering applications to avoid the intrinsic complexity and additional computational effort required by the former. As a result, simplified NSPs recommended in ATC-40 (1996) and FEMA-356 (2000) have become popular. These procedures are based on monotonically increasing predefined load patterns until some target displacement is achieved (Kalkan, E. and Kunnath, S. K, 2006). There are some criterions for assessment of structures behavior in the target displacement. One of these approaches is discussed in FEMA-356 (2000). This method is based on evaluation of plastic rotation of plastic hinges in structural elements. This method is a primitive procedure in assessment of damage parameter in structures. Some researchers have proposed more complicated procedures for assessment of damage parameter. Park et al. (Park et al., 1985) suggested a damage index which is based on deformation and energy concepts in structural elements. For reducing damage index in structures we have to change dimensions of structural elements and amount of used material. This will induce the increase of construction cost. In this paper it is tried to simultaneously reduce the amount of used material in the structure and holding damage index as a constant value or reduce it. For this purpose two reinforced concrete frames which have 4 and 8 stories were selected. For solving this optimization problem genetic algorithm have been applied. The objective function in the GA, as mentioned before, is an index of structure weight, amount of rebar in the beams and columns and overall damage index of structure. After implementation of this algorithm the weight of structure and damage index have been decreased. By using this method the cost of construction is thoroughly reduced and performance of structure is improved.

2. DAMAGE INDEX

One of the most popular damage models which is used in research studies is Park & Ang damage model (Park et al., 1985), this model was incorporated in IDARC program (1996) since the original release of the program.

The Park & Ang damage index for a structural element is defined as:

$$DI_{P\&I} = \frac{\delta_m}{\delta_u} + \frac{\beta}{\delta_u\ P_y}\int dE_h \tag{2.1}$$

Where δ_m is the maximum experienced deformation; δ_u is the ultimate deformation of the element; Py is the yield strength of the element; $\int dE_h$ is the hysteretic energy absorbed by the element during the response history; and β is a model constant parameter. The Park & Ang damage model (Park et al., 1985) accounts for damage due to maximum inelastic excursions, as well as damage due to the history of deformations. Both components of damage are linearly combined. Three damage indices are computed using this damage model:

1. Element damage index: column, beams or shear wall elements.
2. Story damage index: vertical and horizontal components and total story damage.
3. Overall building damage.

Direct application of the damage model to a structural element, a story, or to the overall building requires the determination of the corresponding overall element, story, or building ultimate deformations. Since the inelastic behavior is confined to plastic zones near the ends of some members, the relation between element, story or top story deformations, with the local plastic rotations is difficult to establish. For the element end section damage the following modifications were applied.

$$DI = \frac{\theta_m - \theta_r}{\theta_u - \theta_r} + \frac{\beta}{M_y \theta_u} E_h \tag{2.2}$$

Where θ_m is the maximum rotation attained during the loading history; θ_u is the ultimate rotation capacity of the section; θ_r is the recoverable rotation when unloading; M_y is the yield moment; and E_h is the dissipated energy in the section. The element damage is then selected as the biggest damage index of the end sections. The two additional indices: story and overall damage indices are computed using weighting factors based on dissipated hysteretic energy at component and story levels respectively:

$$DI_{story} = \sum (\lambda_i)_{component} (DI_i)_{component} \tag{2.3}$$

$$(\lambda_i)_{component} = \left(\frac{E_i}{\sum E_i} \right)_{component}$$

$$DI_{overall} = \sum (\lambda_i)_{story} (DI_i)_{story} \tag{2.4}$$

$$(\lambda_i)_{story} = \left(\frac{E_i}{\sum E_i} \right)_{story}$$

Where λ_i are the energy weighting factors; and E_i are the total absorbed energy by the component or story "*i*".
Table 1 presents the calibrated damage index with the degree of observed damage in the structure.

Table 1 Interpretation of overall damage index (1996)

Degree of Damage	Physical Appearance	Damage Index	State of Building
Collapse	Partial or total collapse of building	> 1.0	Loss of building
Severe	Extensive crashing of concrete; disclosure of buckled reinforcement	0.4 - 1.0	Beyond repair
Moderate	Extensive large cracks; spalling of concrete in weaker elements	< 0.4	Repairable
Minor	Minor cracks; partial crushing of concrete in columns		
Slight	Sporadic occurrence of cracking		

3. OPTIMIZATION APPROACH

As it mentioned before for solving the optimization problem, genetic algorithm has been used. Genetic algorithms developed by Holland (Holland J.H., 1975) that combine problem solving algorithms with the principles of evolution demonstrate excellent operations in combinatorial optimization that have a finite solution. Potential solutions are represented as ‘individuals’, combinations as chromosomes, and then they are evolved gradually through the genetic operations such as selection, crossover, and mutation to find optimal solutions. Also, a fitness function, which originates from an objective function of the problem, evaluates each individual. The searching schematics of a simple genetic algorithm can be generalized to the following steps:
Step 1. Organize initial population P(0) of solutions, which includes M number individuals as the initial generation, g=0;
Step 2. Evaluate fitness of all individuals in P(0);
Step 3. Finish operations when the Stop Criterion Satisfied, otherwise proceed to Step 4;
Step 4. Select the more fit individuals based on fitness from P(g) and transform them to new individuals, called offspring. (Lee, C.K. and Kim, S.K., 2007)
In this problem individuals consist of dimension of beams and columns of frame and the amount of rebar area in each of them. For columns one rebar index as the overall rebar area, and for beams two steel indices as top and bottom rebar area of beam have been considered. Columns section is square and beams section is rectangle. Therefore there are two parameters for each beam dimension and one parameter for each column dimension. Consequently each individual has N bit, which N is defined below:

$$N = (NBEAMS + NCOLUMNS) \times (AsBit + DimBit)$$

Where:
N: Number of bits in each individual.
NBeams: Number of beams in structure.
NColumns: Number of columns in structure.
AsBit: Number of bits which used as each rebar steel index (in this research AsBit=12).
DimBit: Number of bits which used as each dimension index (in this research DimBit=9).

For example N for considered 4 story building is equal to 840. The objective function is defined as a function of concrete and rears’ volume, and overall structural damage index. For defining this objective function, weighted sum method has been used. By using penalty method, constraints (e.g. maximum and minimum area of rebar in beams) were applied. The fitness function is defined below:

$$F = (Wd \times Sumd) + (Was \times Sumas) + (Wc \times Sumc) + (Aspen)$$

Where:

Wd: Weight of damage index (in this research Wd=20).
Sumd: Damage index.
Was: Weight of rebar volume index (in this research Was=20).
Sumas: Rebar volume index.
Wc: Weight of concrete volume index (in this research Wc=100).
Sumc: Concrete volume index.
Aspen: Penalty index for controlling range of rebar area.

Each population has 26 individuals. Crossover and mutation ratio were considered equal to 0.8 and 0.01 respectively.

4. MODELING

Two reinforced concrete frames which have four and eight stories were selected. These frames were designed for region of high seismicity in accordance with 2800 code (2005) with considering ACI318-05 (2005) provisions for intermediate moment resisting frames. The soil of the site is assumed to be soil type II according to 2800 code (2005) (similar to soil type C in FEMA 356), a regular building in plan was considered and an interior frame was selected. Building plan and selected frame are shown in Figure 1.

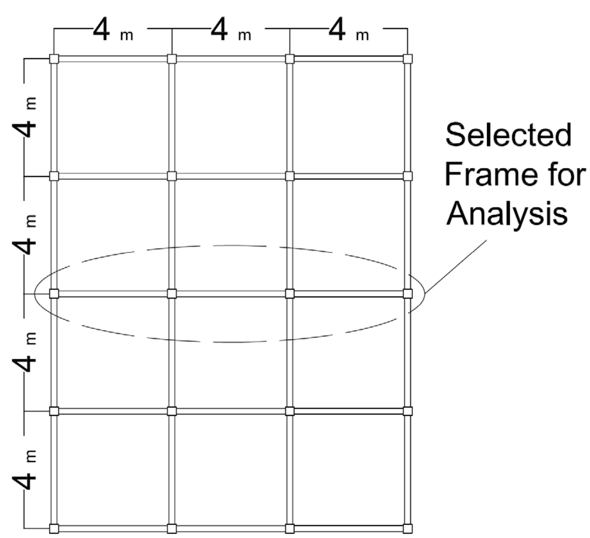

Figure 1 Building plan and selected frame

Concrete compressive strength and yield stress of steel rebar are supposed to be 24 Mpa and 400 Mpa respectively. The dead and live load of stories are assumed to be 700 kg/m^2 and 200 kg/m^2 respectively, consequently the contribution of the selected frame is 2800 kg/m for dead and 800 kg/m for live load.

Table 2 Dimensions of reinforced concrete elements sections

Section Name	Depth	Width
BEAM30X30	30	30
BEAM35X30	35	30
COL35X35	35	35
COL40X40	40	40
COL30X30	30	30
COL45X45	45	45

A typical view of selected frames for analysis is shown in Figure 2. The height of each story is supposed equal to 3 meters.

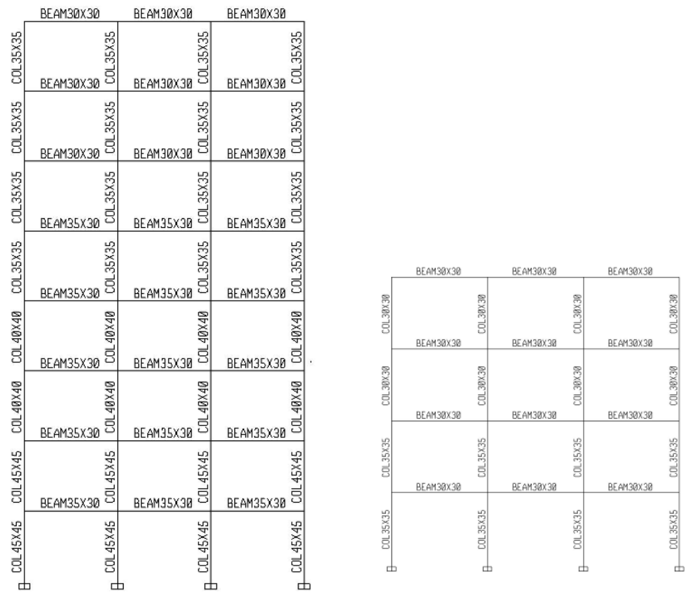

Figure 2 Typical views of selected frames

5. ANALYSIS METHOD

For evaluating the fitness of each individual an ActiveX control has been written by Delphi program (1998). This control gets an individual as a string and gives fitness of it as a real number. The Genetic algorithm has been applied by GA Toolbox in MATLAB program (2005). All nonlinear analyses have been performed by IDARC program (1996). Optimization has been done by following steps and is shown in Figure 3:
Step 1: Generating population in MATLAB program (2005).
Step 2: Sending each individual as a string to ActiveX control.
Step 3: Decoding the string in the ActiveX control and generating the input file of IDARC program (1996) with respect to dimensions and steel areas which are obtained from decoded individual.
Step 4: Running IDARC program (1996) by ActiveX control automatically and generating output file.
Step 5: Reading overall damage index of structure from output file and evaluating fitness with respect to damage index and concrete and rebar's volume.
Step 6: Sending fitness of individual to MATLAB program (2005) as a real number.
Step 7: checking stop criterions in MATLAB (2005) and applying reproductions (selection, mutation and crossover).
Step 8: proceeding to step 2, if the stop criteria is not satisfied.
As mentioned before, push over analysis has been performed as a nonlinear analysis. The load pattern assumed to be triangular as mentioned in FEMA 356 (2000). All structures were pushed to reach the displacement equal to six percent of structure height.

5.1. ActiveX Control

ActiveX control is the software, based on Microsoft's Component Object Model (COM) (1998). It lets a program to add Its functionality by calling that components and it will be appear as normal parts of the program. This type of control can be written in many windows programming languages (e.g. Visual basic, Delphi) and can be used in each language. In this paper the ActiveX control has been written in Delphi programming language (1998) and has been used in MATLAB software.

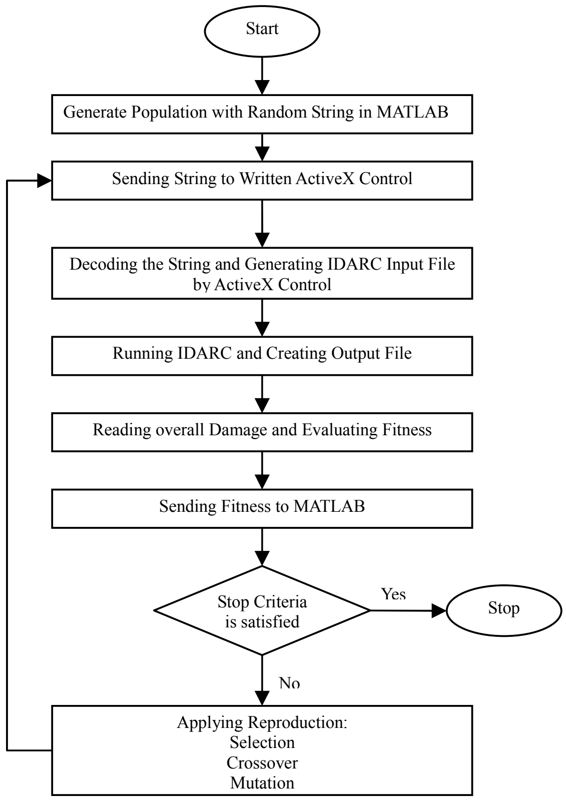

Figure 3 Typical flowchart of analysis method

6. ANALYSIS RESULTS

By method which described in the last section, two RC frames have been analyzed and Results are presented here. Genetic algorithm convergence graph are shown in Figures 4 and 5.

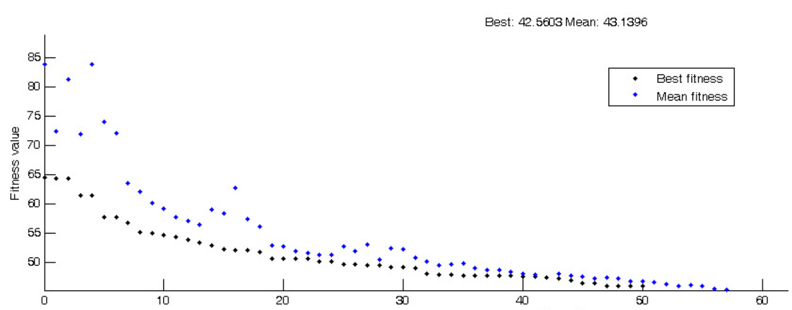

Figure 4 Genetic algorithm convergence graph for 4 story frame

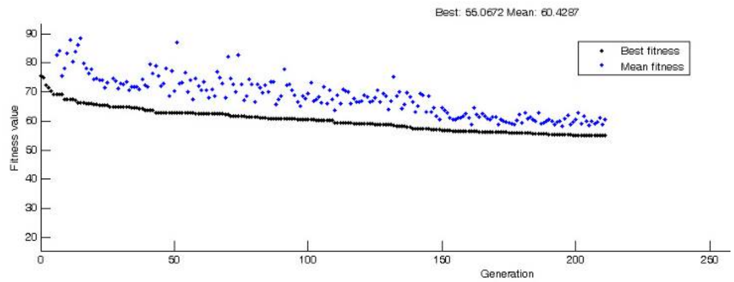

Figure 5 Genetic algorithm convergence graph for 8 story frame

As it is shown in the last figures, the algorithm converged after performing some generation steps. Comparison between the original design and the results of this algorithm is shown in table 3.

Table 3 Comparison between original design and analysis results

	Original design			Analysis Results		
Frame Number	Concrete Volume	Rebar steel volume	Overall Damage Index	Concrete Volume	Rebar steel volume	Overall Damage Index
4-story	12.33	0.196	0.246	7.33	0.172	0.144
8-story	27.6	0.696	0.258	32.13	0.549	0.224

7. CONCLUSION

By using this method the cost of construction will be decreased. The damage index can predict behavior of structure more accurate and can be used as a parameter to measure performance of structures. With respect to analysis results, in the 4 story frame the volume of concrete and rebar steel decreased 41 and 13 percents respectively. Also overall damage index reduced. In the 8 story frame the volume of concrete and rebar steel decreased 14 and 22 percents respectively. Also overall damage index reduced. Therefore this method can be used to optimal analysis of structures.

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